Use of Multifrequency Airborne Radar Measurements for GPM Algorithms

Gerald Heymsfield[1], Lin Tian[1,2], Mircea Grecu[1,2], Vijay Venkatesh[1,3]

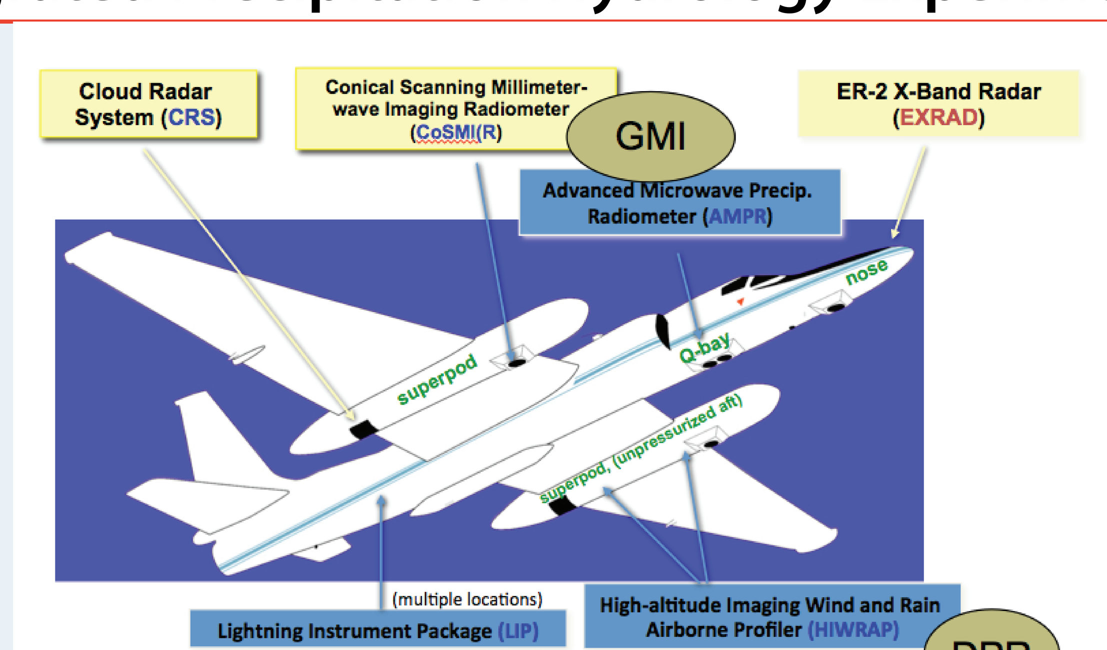
[1]Goddard Space Flight Center, [2]GESTAR/Morgan State University, [3]SSAI, Inc.

Objectives

- NASA's Global Precipitation Mission (GPM) and Aerosol Chemistry Ecosystem (ACE) Mission Formulation have conducted two recent field campaigns using the instrumented NASA ER-2:
  - May-June, 2014: Integrated Precip. and Hydrology Experiment (IPHEx)
  - Nov-Dec, 2015: Radar Definition Experiment(IPHEx)/OLYMPEx
- Here we highlight a few cases from the IPHEx and RADEX campaigns with emphasis on the ER-2 radar measurements, and preliminary microphysical retrievals.
- NASA ER-2 remote sensing aircraft was instrumented with 3 radars @ 4 frequencies from X- to W-band. Also, the UND Citation, ground-radars, and DC-8 (OLYMPEx) participated.

"Column physics" has been a high priority in these campaigns, to better understand what is observed from spaceborne radars and radiometers, and the characteristics of clouds and precipitation below.

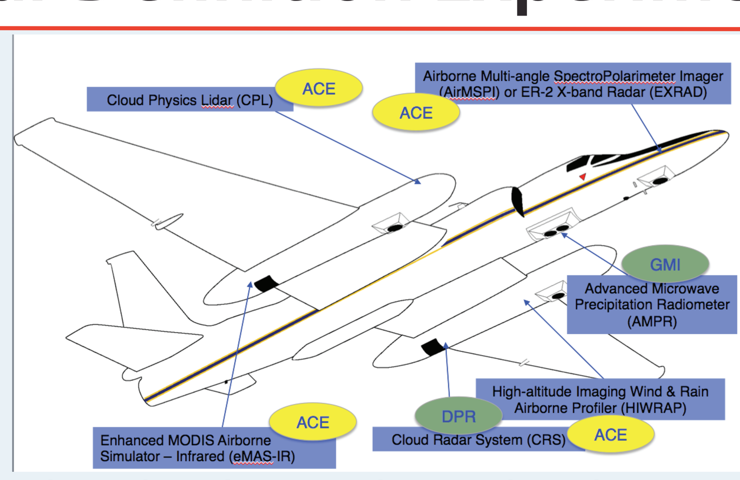
Integrated Precipitation Hydrology Experiment (IPHEx)



Radar: 9.6, 13.5, 35., 94 GHz
Radiometer: 10.7 (H&V), 19.35 (H&V), 37.1 (H&V), 50.3, 52.6, 85.5(H&V), 89 (H&V), 165.5 (H&V), 183.3+/1, 183.3+/-3, 183.3+/-7 GHz

- 15 science flights that sampled a variety of precipitation systems.
- Coordinated flights with UND Citation in situ aircraft.
- 3 land-based calibration flights for radiometer/radar background statistics, for better PIA estimates .
- Radar calibration manuevers during 3 over water flights.
- 5 GPM underpasses (2 within DPR swath); one with precipitation
- 1 TRMM underpass; 1 CloudSat underpass during clear conditions.

ACE Radar Definition Experiment (RADEX)

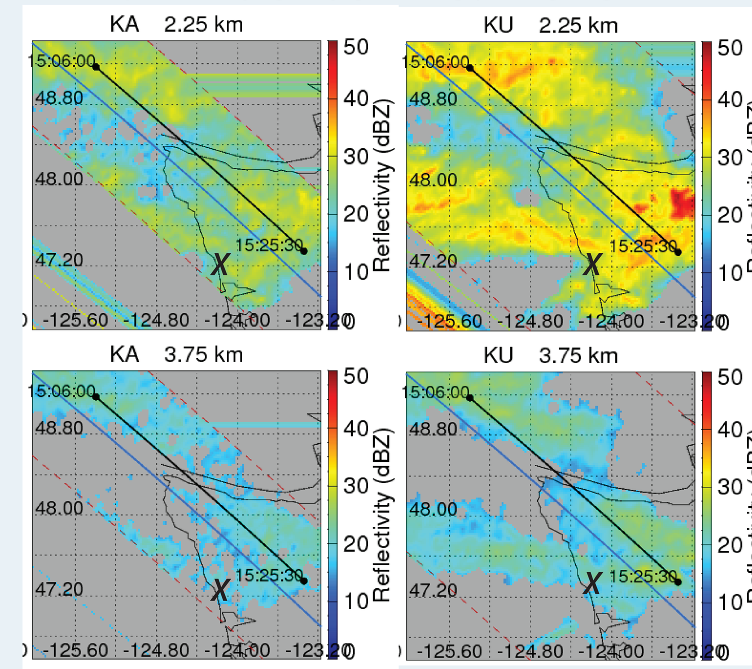


- 12 science flights closely coordinated with DC-8 and UND Citation
- 3 Dec 2016 was excellent case with GPM overpass.

Date	Description	ER-2	EXRAD	HIWRAP	CRS	DC-8	Citation
10-Nov-16	Ridge condition with little precip over mountains		Y	Y	Y		
18-Nov-16	Shallow post-frontal convection with an overrrunning altostatus ice layer	1759-0033	N	Y	Y	1826-0025	2130-0021
23-Nov-16	Wide zone of precip in an approaching weak trough and collapsing frontal system	1402-2214	Y	Y	Y	~1534-2156	~1500-1800, 2030-2330
24-Nov-16	Part 2 of dying frontal system, weak snow at hurriane ridge, postfrontal clouds	1508-2216	N	Y	Y	1345-2018	1612-1740, 1853-2142
1-Dec-16	Weak trough and front with extensive stratiform modified by topography	2103-0208	Y	Y	Y	2056-0148	2247-0148
3-Dec-16	Complex baroclinic system with orographically enhanced rain & GPM overpass	1408-1733	Y	Y	Y	1430-1721	1403-1710
4-Dec-16	Post frontal convection over the ocean and mountains	1305-2006	N	Y	Y	1259-1753	1306-1601, 1708-2006
5-Dec-16	Broad frontal cloud system with strong wind shear	1359-1757	Y	Y	Y	1353-1854	1435-1805
8-Dec-16	Orographic enhancement of an "Atmospheric River"	1827-~0030	Y	Y	Y	1308-2019	
10-Dec-16	Occluded front and post-frontal convection	1434-1702	N	Y	Y	1451-2005	1434-1702
12-Dec-16	Precipitation associated with an occluded front and warm sector	1800-2206	Y	Y	N	1549-2155	1657-2013
13-Dec-16	Convection following the passage of an occlusion	1603-0002	N	Y	N	1352-1852	1552-1910, 2005-2319

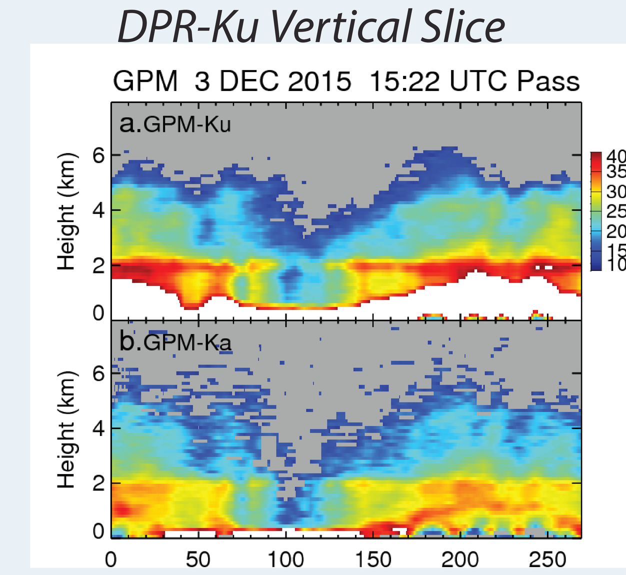
RADEX/OLYMPEX: GPM Overpass / Aircraft Coordination on 3 Dec 2015

DPR-Ku Swath ~15:22 UTC

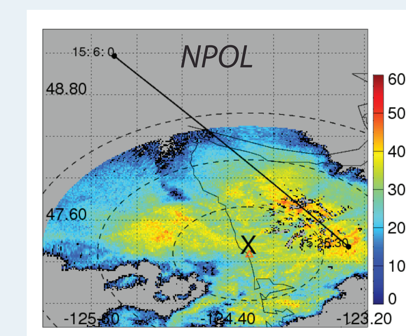


DPR Ku and Ka-band reflectivity at 2.2 km altitude and 3.75 km. DPR data is interpolated and mapped to uniform grid. Solid black line is the ER-2 track. Blue line is satellite nadir. This and other DPR plots use ZFactorMeasured reflectivity. NPOL position is marked with an "X".

DPR-Ku Vertical Slice

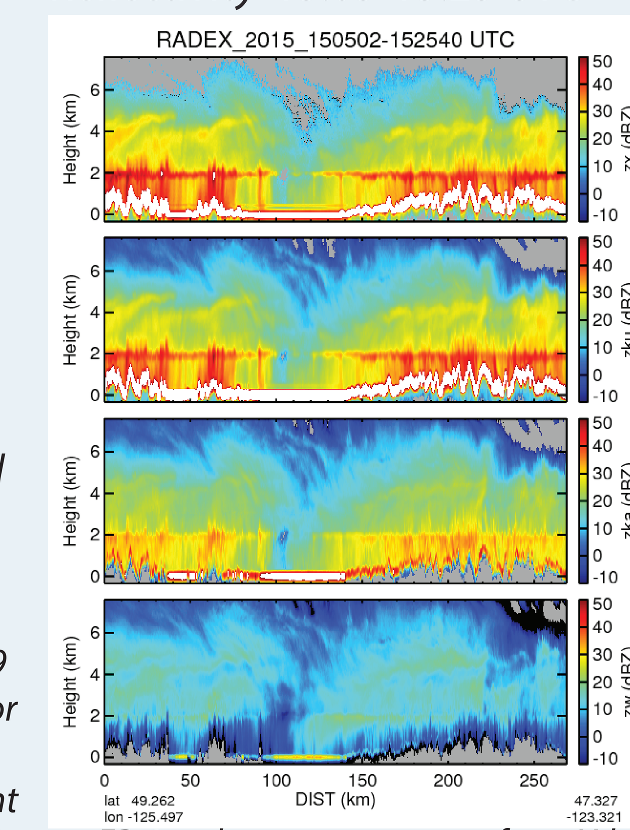


DPR Ku and Ka-band reflectivity interpolated to ER-2 radar profiles. Olympic mountains are white region in top plot.



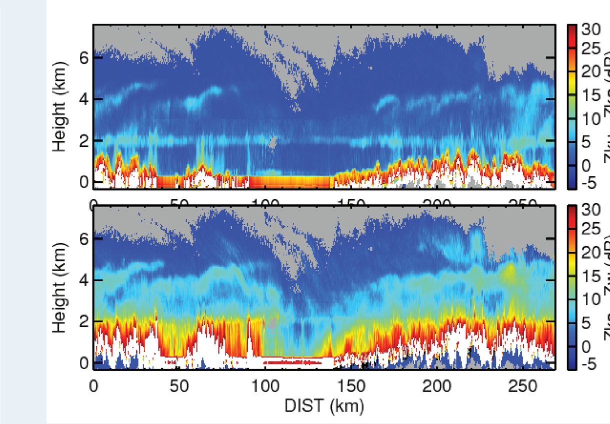
NPOL PPI scan at 15:19 UTC and 1.5 degrees for same region as DPR section to left.ER-2 fight track is shown by black line and NPOL position is marked with an "X".

ER-2 Radar 4-frequency Reflectivity 15:05-15:25 UTC



ER-2 radar measurements from X-band (top) to W-band (bottom). Melting layer is at approximately 2 km. Peaks in Olympic Mountains are obvious on right side of plots.

ER-2 Radar Dual-Frequency Ratio



Dual-frequency ratios (above): DFR (Ku/Ka) and DFR (Ka/W). These values are not attenuation corrected. The DFR (Ka/W) is enhanced above the melting level possibly due to a combination of ice particle characteristics and particle phase.

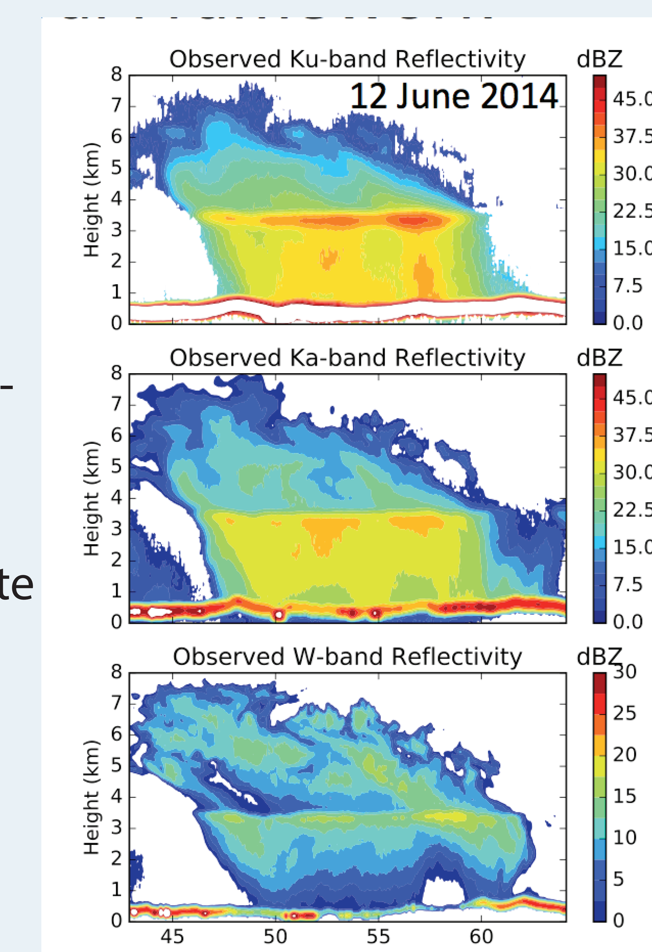
Radar Retrieval - IPHEx - 12 June 2014

Radar Retrieval Framework

- Dual-frequency (Ku/Ka) radar profiling algorithm (Grecu et al., 2011, J. Appl. Meteor. Climatol.) with improvements for the addition of W-band & ice phase.
- Derive ensemble of Nw-dependent, Ka-band retrievals
- Simulate W- (Ku-) band reflectivity observations from the Ka- retrievals
- Adjust Ka-band retrievals to maximize the agreement between simulated and observed W- (Ku-) band reflectivity

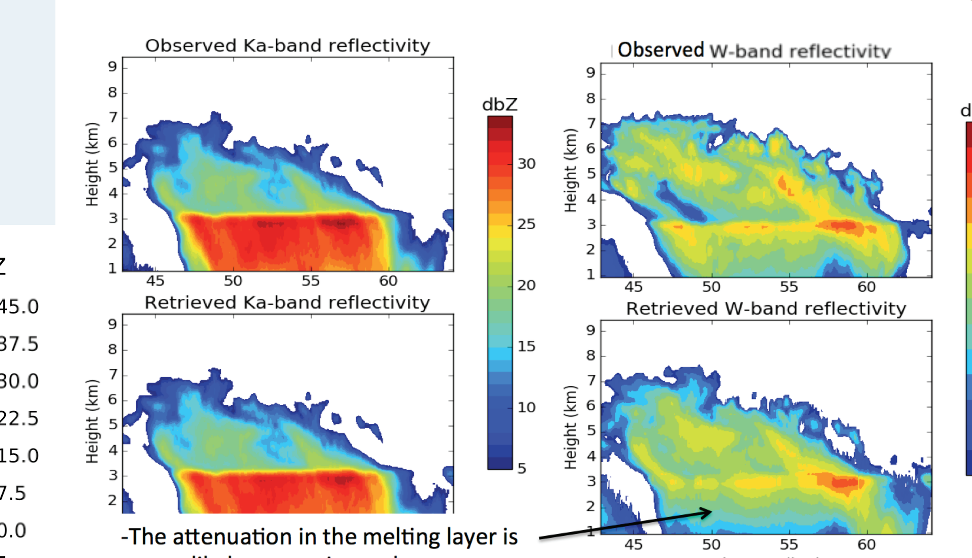
Assumptions:

✓ Particles sizes are parameterized using normalized gamma distributions.
✓ m is assumed known, while Nw and Dm are retrieved.
✓ Dm is retrieved for every gate, while Nw is retrieved for every gate above the freezing level and assumed constant below frz level.
✓ All the other variables (e.g. precipitation water content, precipitate rate, etc.) are derived from Nw, Dm and m.
✓ Rayleigh Gans approximation (Westbrook et al. 2008) used at W-band.
✓ Masunaga et al. (2010) model is used to derive the electromagnetic properties in the melting layer.
✓ The fast multiple scattering model of Hogan and Battaglia (2008) is incorporated into the framework.
✓ No significant multiple scattering effects are predicted by the model for the June 12, 2014 case.
✓ Mie calculations for snow based on the soft sphere approximation assuming constant density (e.g. r=0.1gcm3).

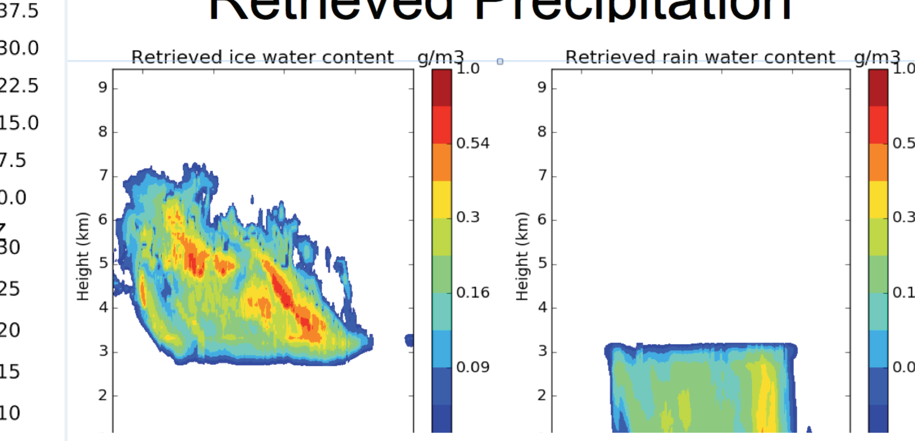


Observed W, Ka, and Ku-band Reflecitivity from 12 June 2014.

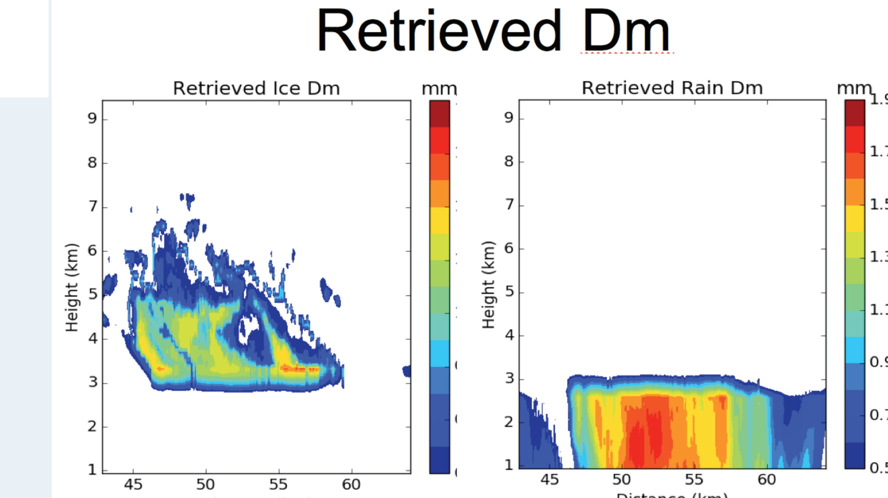
Observed and Retrieved Reflectivity



Retrieved Precipitation



Retrieved Dm



Relevant Papers

Heymsfield, G.M. and co-authors, 2013: Airborne radar observations of severe hailstorms Implications for future spaceborne radar. J. Appl. Meteor. Clim., 52, 1851-1867.

Battaglia, A., and co-authors, 2016: Using a multiwavelength suite of microwave instruments to investigate the microphysical sturcture of deep convective cores. J. Geophy. Res., 9356-9381.

Grecu, M., L. Tian, W. S. Olson, S. Tanelli, 2011: A robust dual-frequency radar profiling algorithm. JAMC, 1543-1557.

Future Work

- Coordinated observational studies between ER-2, Citation, and ground radars for IPHEx and RADEx cases.
- Prepare cases (further QC, etc.) for radar and combined retrieval studies.
- Perform radar/combined retrievals (Grecu).
- Quantitative radar comparisons with GPM, DC-8, and ER-2 radars.
- Examine beam filling, multiple scattering, etc. with data sets.